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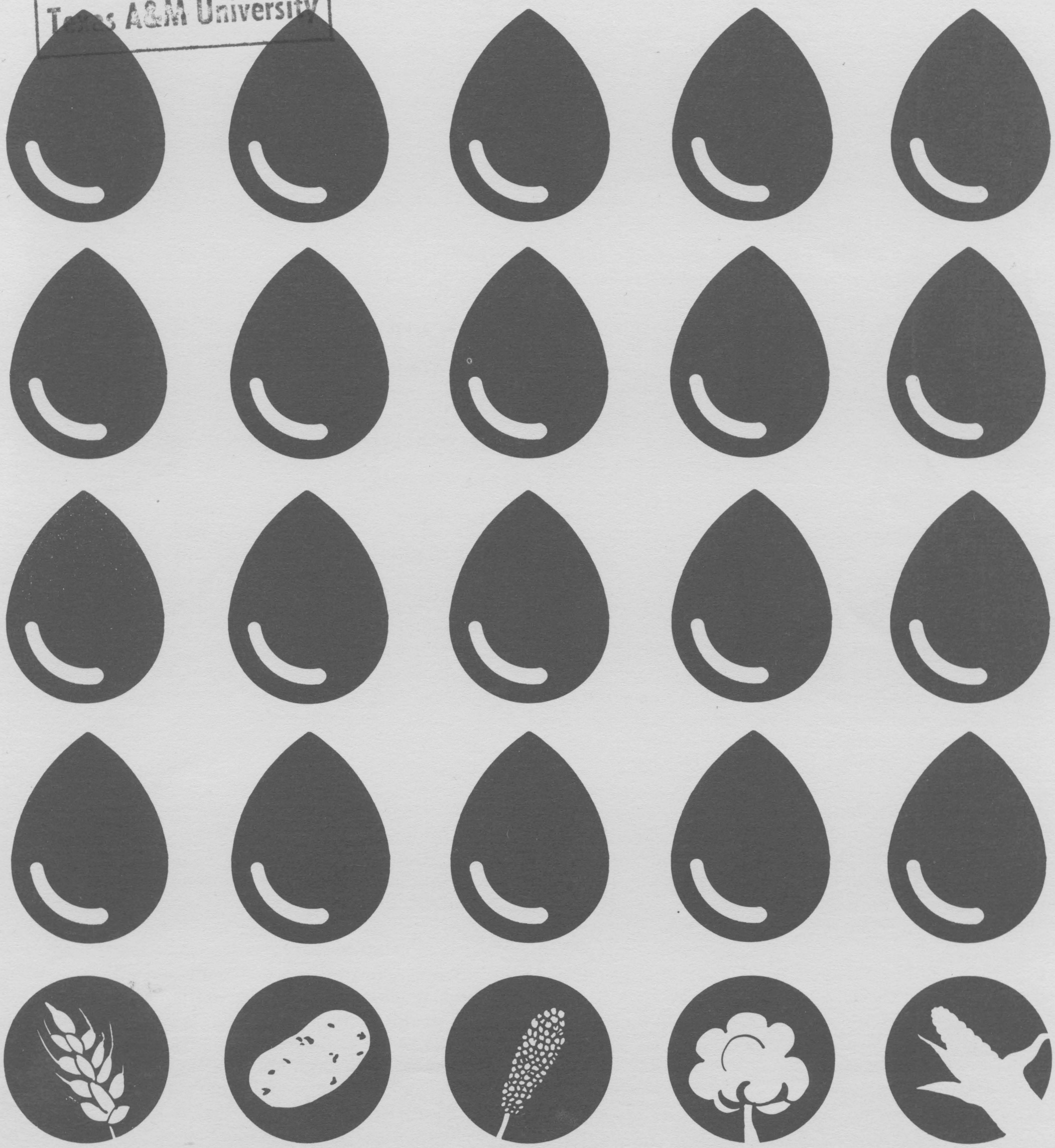
Water Management Studies

In the Rolling Plains



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SUMMARY

Water management studies were conducted with cotton, grain sorghum, wheat, potatoes, and sweet corn from 1976 through 1978. These studies demonstrated that water is the dominant factor influencing yields in the Rolling Plains.

Yields of cotton, grain sorghum, potatoes, and sweet corn were a linear function of applied water and water use. Moisture need and average rainfall patterns at Chillicothe and Iowa Park showed that irrigation often is not needed for production of 30 to 50 bushels of wheat per acre.

Water Management Studies

In the Rolling Plains

C. J. Gerard, D. G. Bordovsky, and L. E. Clark*

Crop production in the Rolling Plains is dependent upon the effective utilization of rainfall and, sometimes, supplemental irrigation. Although irrigation is practiced on only a small percentage of the area in the Rolling Plains, the amount is significant. For example, in the Knox county area about 1,000 to 1,300 acres of irrigated potatoes and about another 50,000 acres of irrigated field crops are grown. The Wichita Falls Irrigation District is an area growing irrigated crops such as cotton, Coastal bermudagrass, pecans, and vegetables.

The irrigated acreage probably will always be small compared to that in dryland and rangeland agriculture because water production from the shallow reservoirs in the Rolling Plains is often limited; however, the water is often of excellent quality for irrigation of agricultural crops and relatively inexpensive to pump. Because of the relatively low pumping costs, there seems to be potential for considerably more irrigation. Potential projects for improving the water quality in the Red River Basin could further improve and increase the potential for irrigation along the rivers in this section of Texas. It is important, therefore, that the response of different crops to irrigation and rainfall in the Rolling Plains be better understood and defined.

Efficient use of water is dependent upon an understanding of the role of soil properties on the available water and nutrient reservoirs of different soils, the permeability of soil to water and plant roots, and the available water-holding capacities of these soils. Kramer, Biddulph, and Nakayama (7) stated that the most important feature of annual crop root systems is their rapid extension into previously unoccupied soil. It is this continuous invasion of new soil mass that enables plants to grow for days or weeks without rain or irrigation. The role of soil properties on adaptability and management requirements for different crops in South Texas was recently described by Gerard, Hipp, and Reeves (3). Effective storage and utilization of rainfall in the soil reservoir exploited by plant roots are dependent upon climatic conditions and on soil and crop management practices. Management studies were conducted at different locations to determine the response of important crops in the Rolling Plains to water. Such studies are essential to a better understanding of the interactions of crops with soils, climate, and management, which is necessary for efficient water use for crop production.

CROP WATER REQUIREMENT

Water is one of the most important factors influencing crop yields. Water use or evapotranspiration by plants is dependent upon climatic conditions, available soil moisture, and stage of plant growth.

If a crop is grown under climatic conditions which create high evaporative demands, the consumptive use of water by the crop is high. High temperatures, high light intensities (solar radiation), low humidity, and high wind speeds create an environment of high evaporative demand or high water use. In contrast, low temperatures, low light intensities, high humidity, and low wind speeds create an environment of low evaporative demands or water needs. Cotton and grain sorghum are grown under conditions of high evaporative demand during the spring and summer, while small grains are grown under conditions of low evaporative demand during the fall and winter. Thus, water use by crops is influenced by variations in climatic conditions within and between years.

Soil conditions such as available soil moisture, soil fertility, and compaction can also influence the water use of crops. Management practices such as tillage can influence soil conditions and thus the water use by crops.

Water use by plants is low during the early vegetative growth period but increases rapidly as the vegetative growth or leaf area index (LAI) increases. Leaf area index is the leaf area divided by the land area. Leaf area

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indices during early stages of plant growth will be close to zero, but as plants increase in size and vegetative growth, LAI values can be several times greater than one. Generally water use by crops reaches a maximum during the reproductive stage of plant growth when vegetative growth and LAI are high. At maturity, when the vegetation dies and LAI decreases, the water use by plants decreases and eventually becomes only evaporation from the soil.

Water use by crops is thus influenced by several factors and their ever-changing interaction with each other. Research over a number of years is needed to obtain an average measure of the influence of these factors and their interaction on water use.

The critical stages of plant growth with respect to water are often considered the period just prior to, during, and just after the reproductive stage. Stress or deficiencies during these stages of plant growth can cause substantial yield reductions. In the Rolling Plains water is often deficient and the dominant factor which limits crop production. However, significant rainfall during the critical stages of growth can often cause plants which have been subjected to prolonged stress to produce high yields. This is due to the ability of plants to recover from severe stress and become productive when moisture conditions become favorable. Applying supplemental irrigations during these critical stages of growth is an efficient way of utilizing water for increased yields.

Some plants have the ability to recover from stress or are more drouth tolerant than others. In fact some plants under stress can become almost dormant. For example, stress conditions created by lack of available moisture, high temperature, or both, will sometimes cause cotton to cease fruiting (cutout). However, cotton which has cutout due to stress has often shown the ability, when conditions become favorable, to initiate fruiting again, thereby producing a second crop (2). The precise conditions causing this have not been defined.

Water management studies under field conditions which can monitor the roles of different factors and their interactions are needed for better understanding of the response of different crops to rainfall and supplemental irrigation in the Rolling Plains. The roles of these factors and their interactions on water needs and requirements of different crops are complex. However, the findings generated from the studies reported here should contribute to the more efficient use of water, rainfall, and supplemental irrigation for crop production in the Rolling Plains.

COTTON

Summary

Cotton yields were a linear function of applied water and water use. Three irrigations of about 2.75 to 3 inches per irrigation during the blooming and fruiting period increased cotton yields from about 300 to 900 pounds per acre. Cotton produced about 50 pounds per inch of water. Results in 1976 and 1977 indicated that about 16 and 20 inches of water were used to produce about 750 and 1,000 pounds of lint cotton per acre, respectively. These studies demonstrated that the critical stage of plant growth is the blooming and fruiting period and that some varieties such as Lockett 77 and Tamcot SP-37 are more efficient than others in the use of water.

Methods and Materials

A moisture level-variety-fertility experiment was conducted with cotton on the Abilene clay loam soil at Chillicothe in 1976. Because fertility did not influence yields in 1976, the study was changed to a moisture level-variety-chiseling study in 1977. Four moisture levels (Table 1) were randomized in a Latin square. Cotton was planted in 40-inch rows, and each moisture level treatment was 24 rows wide and 75 feet long. Moisture level treatments consisted of none, one, two, and three irrigations with approximately 2.75 to 3 inches of water applied per irrigation.

The moisture level treatments were split to include two varieties, Lockett 77 and Lankart 611. Variety plots were 12 rows wide. In 1976, treatments of 0, 40, and 80 pounds of nitrogen per acre (N/A) were subplots of varieties. Nitrogen treatments were four rows wide. In 1977, varieties were split to include non-chiseled and chiseled treatments. Plots for these treatments were six rows wide.

Cotton varieties Lankart 611 and Lockett 77 were planted on May 20, 1976, and June 2, 1977. Chiseled treatments in 1977 consisted of ripping the middle of rows 12 inches deep on July 11.

Water was metered onto plots using gated pipe. Soil moisture at different depths to 12 inches below the surface was determined at different times during the growing season using a neutron probe. Soil moisture in the surface 12 inches of soil was determined gravimetrically. Water use by cotton on different treatments was determined.

Blooming as influenced by moisture levels and varieties was determined on selected 10-foot increments of row by counting blooms daily. Plant height, leaf area

TABLE 1. DESCRIPTION OF MOISTURE LEVEL-VARIETY EXPERIMENT CONDUCTED ON ABILENE CLAY LOAM SOIL IN 1976 AND 1977

Moisture level treatments[ab]	Description	Available soil moisture at time of irrigation[a]	No. of irrigations
A	Non-irrigated		0
B	Irrigation at first bloom	25-30%	1
C	Irrigation at first bloom plus One irrigation[c]	25-30%	2
D	Irrigation at first bloom plus 2 irrigations[c]	25-30%	3

[a]Moisture levels were 24, 40-inch rows wide. Percentages refer to available soil moisture in effective root zone (top 2 feet of soil).

[b]Varieties were 12, 40-inch rows wide.

[c]Intervals between 1st and 2nd and 3rd irrigation were 20 and 15 days, respectively.

indices, and fruit shedding of cotton as influenced by varieties and moisture levels as a function of time were evaluated.

Yields, as influenced by treatments, were evaluated by machine harvesting two center rows (140 feet) of each plot in November. Lint percentages were determined, and yields were converted to lint cotton per acre. Fiber qualities as influenced by treatments and varieties were measured. The data were statistically analyzed, and relationships between yield and water applied plus rainfall during blooming and fruiting period and water use were calculated.

Results

Blooming and Leaf Area Index Data

Average blooming of varieties as a function of time in 1976 is shown in Figure 1. Irrigation had little or almost no influence on blooming. However, Lockett 77 had about 10 percent more blooms than Lankart 611. High temperatures for an extended period of time or related high stress caused early cut-off of fruiting in 1976 (Figure 2).

Blooming as a function of time, varieties, and irrigation treatments in 1977 on Abilene clay loam soil is represented in Figures 3 and 4. The blooming of non-irrigated Tamcot SP-37 was taken from a 16-row border area adjacent to irrigation treatments (Figure 3). Blooming by non-irrigated Lockett 77 and Tamcot SP-37 was considerably higher than that of Lankart 611. Lockett 77

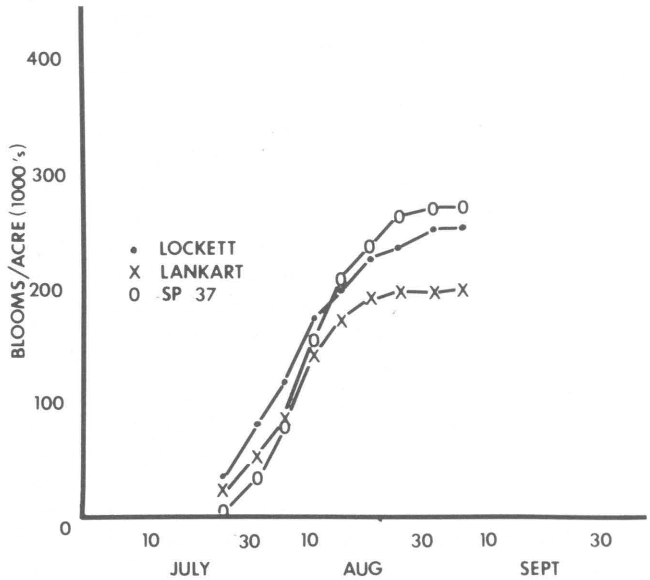

Figure 3. Influence of varieties when not irrigated on accumulative blooming as function of time on Abilene clay loam, 1977.

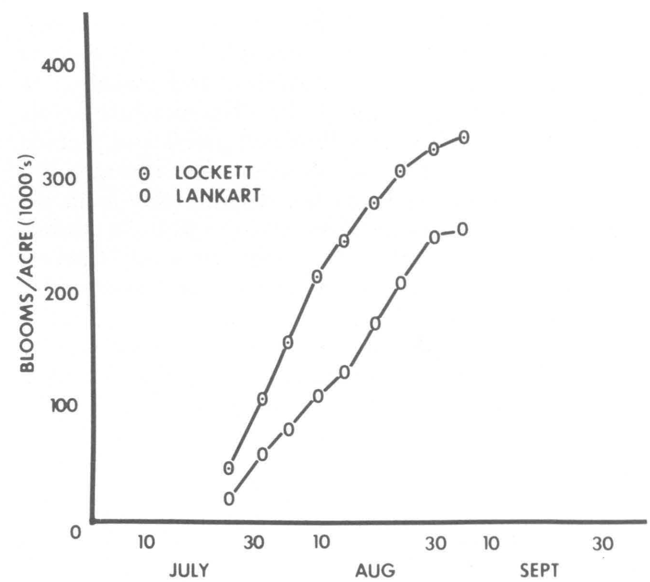

Figure 4. Influence of three irrigations on accumulative blooming by two varieties on Abilene clay loam, 1977.

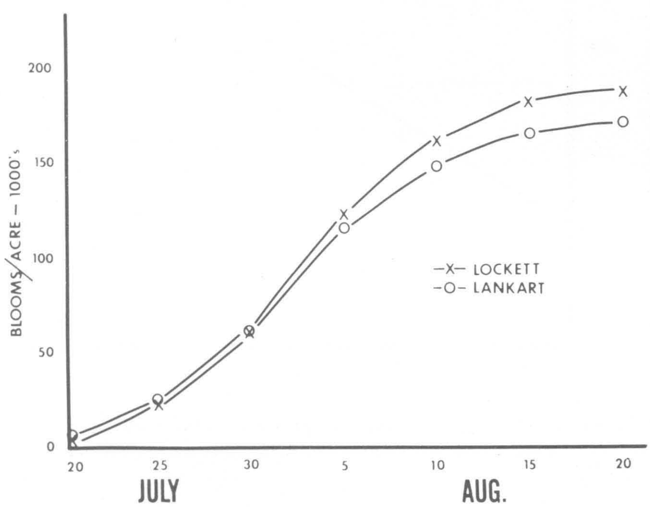

Figure 1. Average blooming as a function of time by Lankart 611 and Lockett 77, 1976.

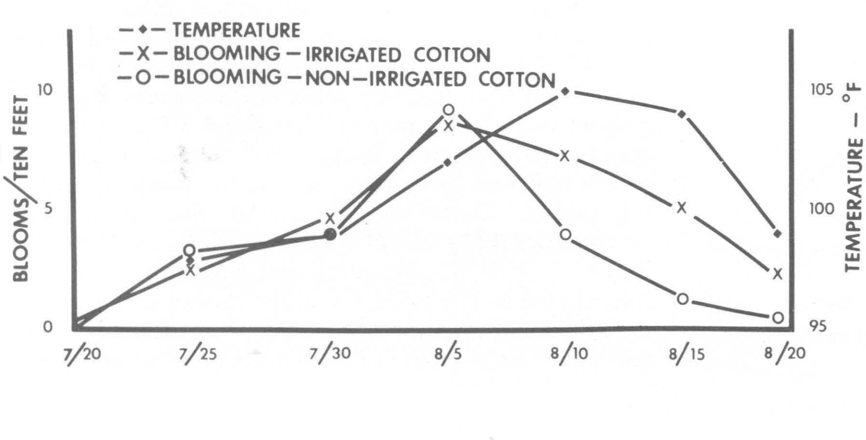

Figure 2. Blooming and temperature data for non-irrigated and irrigated cotton in 1976.

irrigated three times (Figure 4) in 1977 had higher blooming than non-irrigated cotton (Figure 3) and considerably higher accumulative blooming than irrigated Lankart 611 (Figure 4).

Leaf area indices of non-irrigated Lankart 611, Lockett 77, and Tamcot SP-37 on Abilene clay loam in 1977 are presented in Figure 5. Cotton production by non-irrigated Lockett 77, Lankart 611, and Tamcot SP-37 averaged 376, 435, and 463 pounds of lint cotton per acre, respectively. In 1977, hot, dry conditions during September and October caused cotton bolls to be more open than usual, resulting in considerable lint loss. Lockett 77 was one of the more susceptible varieties, and estimated lint losses by this variety ranged from 15 to 30 percent. Leaf area indices of Tamcot SP-37, although it yielded very well, were considerably lower than those of the other two varieties in 1977. These results suggest that certain varieties may use water more efficiently than other varieties. Relationships between yield and LAI for Lankart 611 and Lockett 77 for 1976 and 1977 are reported in Figures 6 and 7, respectively. These relationships, in addition to yield data which will be discussed later, indicate that Lockett 77 is more efficient in the use of water than Lankart 611.

Yield Data

Yields, as influenced by irrigation treatments, varieties, and N in 1976 are reported in Table 2. Results from irrigation treatments, varieties, and chiseling in 1977 are reported in Table 3. In 1976 moisture levels and varieties significantly influenced yields and pounds of cotton produced per inch of water, but nitrogen did not increase cotton yield on the Abilene clay loam. In 1968, Mulkey (9) reported a response to 20 to 40 pounds of N/A by cotton on Miles fine sandy loam soil. Lockett 77 was a more efficient user of water than Lankart 611. Years modified the effects of treatments and varieties (Table 3). This was due to lint losses on the ground by Lockett 77 which was not irrigated and that irrigated once. This was discussed previously. However, (Table 3) Lockett 77 irrigated two and three times during blooming and fruiting periods was a more efficient user of water than similarly treated Lankart 611.

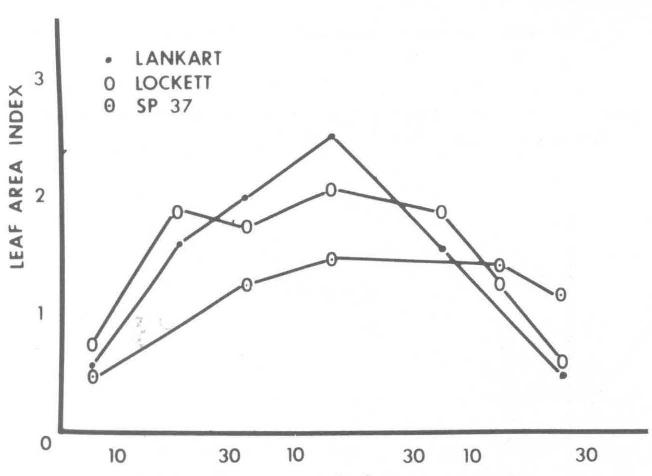

Figure 5. Influence of varieties when not irrigated on leaf area indices as a function of time on Abilene clay loam, 1977.

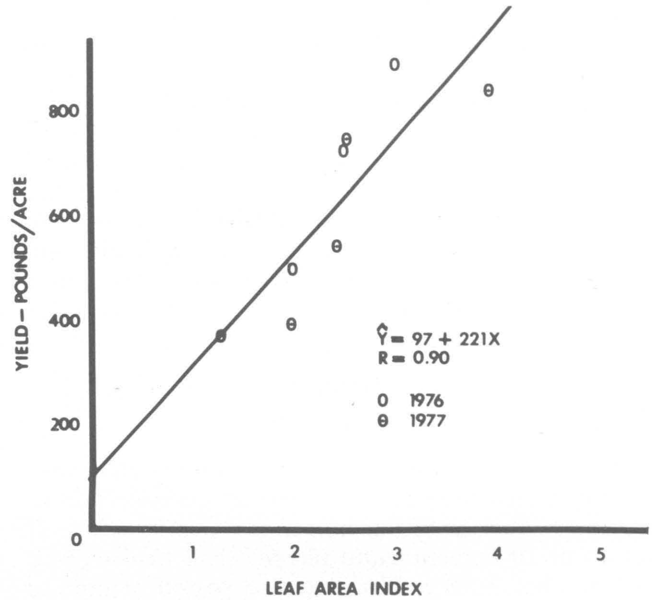

Figure 6. Relationship between average leaf area index during blooming and fruiting period and yield of Lockett 77 in Rolling Plains, 1976 and 1977.

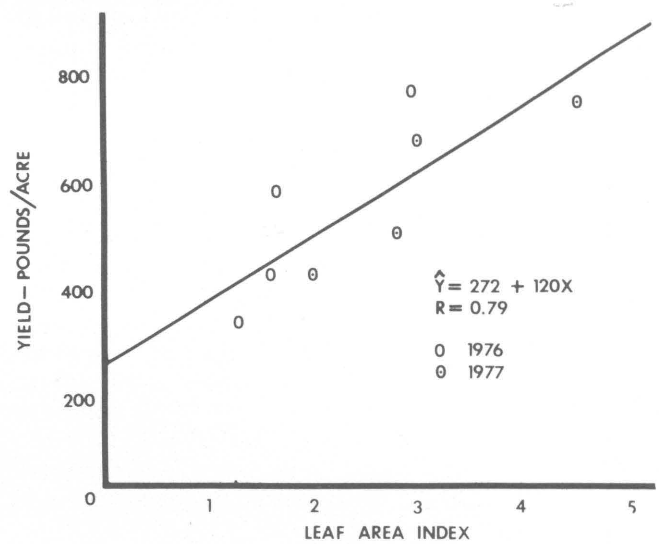

Figure 7. Relationship between average leaf area index during blooming and fruiting period and yield of Lankart 611 in Rolling Plains, 1976 and 1977.

Relationships between yields of lint cotton per acre on Abilene clay loam soil in 1976 and 1977 and water applied plus rainfall during the blooming and fruiting period and water use are reported in Figures 8 and 9, respectively. Yields ranged from about 300 pounds per acre by dryland cotton to about 900 pounds per acre by cotton irrigated three times during blooming and fruiting period. These data emphasize that the critical demand period by cotton as has been reported for South Texas (3) (4) is the blooming and fruiting period. The importance of the need for water during this stage of growth is indicated by the relationship between yield and water use in inches per day during the blooming and

TABLE 2. YIELDS OF LINT COTTON AS INFLUENCED BY MOISTURE LEVELS, VARIETIES, AND N ON ABILENE CLAY LOAM SOIL, 1976

Moisture level treatments[a]	Lankart 611[a]					Lockett 77					Overall average
	Nitrogen, pounds/acre					Nitrogen, pounds/acre					
	0	40	80	Average	lb/in H_2O	0	40	80	Average	lb/in H_2O	Lb/Acre
A	342	355	341	346	45	385	379	365	376	49	361
B	414	439	446	433	40	495	482	530	502	46	468
C	620	571	585	592	46	756	724	713	731	57	662
D	761	785	782	776	51	890	927	876	898	59	837
Average	534	538	539	537	46	632	629	616	627	53	

[a]Moisture level treatments and varieties significantly influenced yields at 1% level.

TABLE 3. YIELD OF LINT COTTON AS INFLUENCED BY MOISTURE LEVEL, VARIETIES, AND TILLAGE IN 1977

Number of Irrigations	Lint cotton/acre				lb/in of H_2O	
	Lankart 611		Lockett 77		Lankart 611	Lockett 77
	Not chiseled	Chiseled	Not chiseled	Chiseled		
0	422	448	376	373	47	41
1	499	527	500	532	40	40
2	689	684	708	762	46	49
3	738	771	794	888	43	48
Average	587	608	595	639	44	45

Treatments significantly influenced yields at the indicated probability levels:
- Moisture levels — 0.01.
- Tillage treatments — 0.05.
- Tillage-moisture level and tillage variety interactions — 0.10.

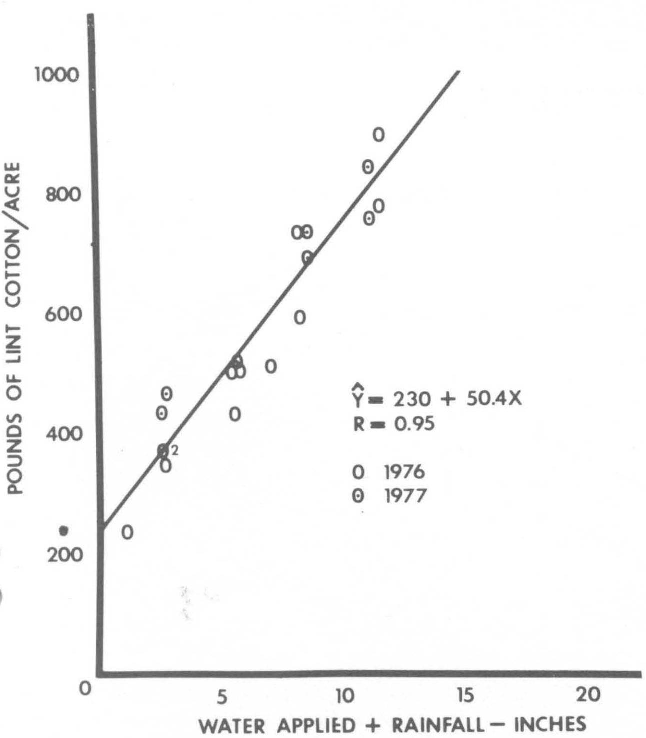

Figure 8. Relationship between water applied plus rainfall during blooming and fruiting period and cotton yields in the Rolling Plains, 1976 and 1977.

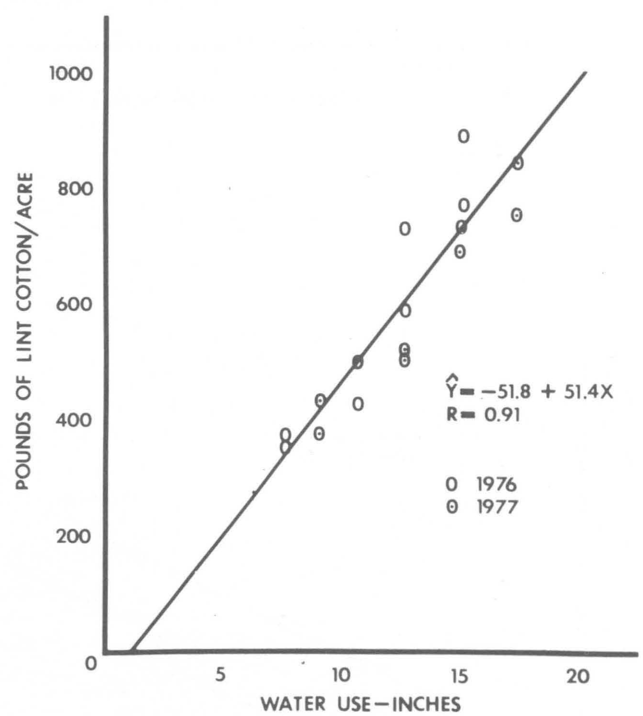

Figure 9. Relationship between yield and water use by cotton in the Rolling Plains, 1976 and 1977.

fruiting period (Figure 10). The relationship between yields and water applied plus rainfall and water use are linear and highly significant. Obviously water is the dominant factor which determines cotton yields in the Rolling Plains. Production of lint cotton per inch of water averaged 51 pounds (Figure 9).

Accumulative potential evapotranspiration and average accumulative water use by cotton irrigated two and three times in 1976 are shown in Figure 11. Before blooming, actual evapotranspiration was low and considerably less than potential evapotranspiration. However, after blooming, cotton irrigated two and three times used about 0.9 and 1.05 times potential evapotranspiration, respectively (Figure 11). Evapotranspiration was estimated according to Jensen's method (6) and from climatic data obtained from the Texas Agricultural Experiment Station at Munday, Texas.

These data emphasize that (a) water is the dominant factor which influences cotton yields, (b) the blooming and fruiting period is the critical stage of plant growth, and (c) some varieties such as Lockett 77 and Tamcot SP-37 are more efficient users of water than varieties such as Lankart 611.

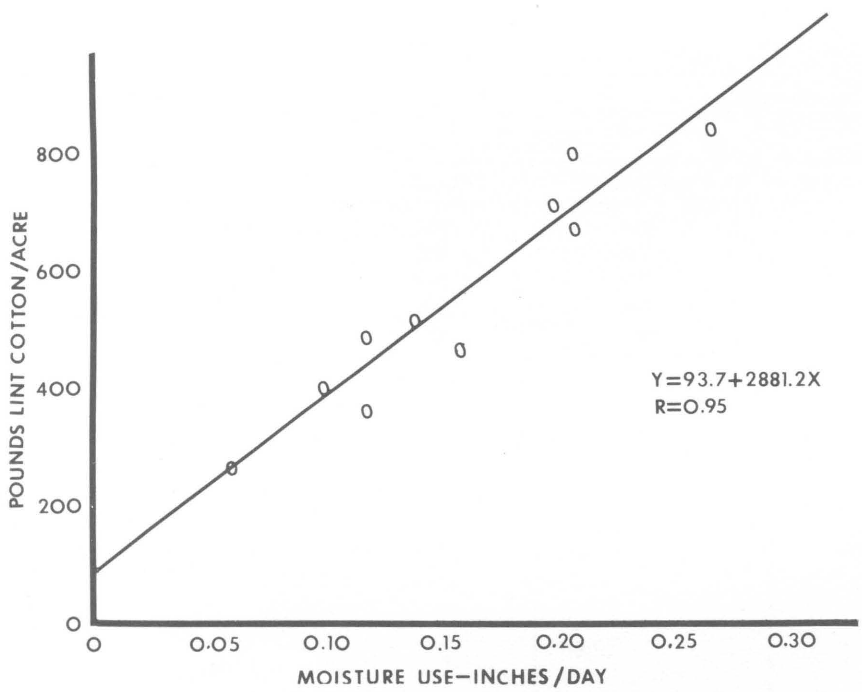

Figure 10. Relationship between water use in inches/day during the blooming and fruiting period and cotton yields, 1976 and 1977.

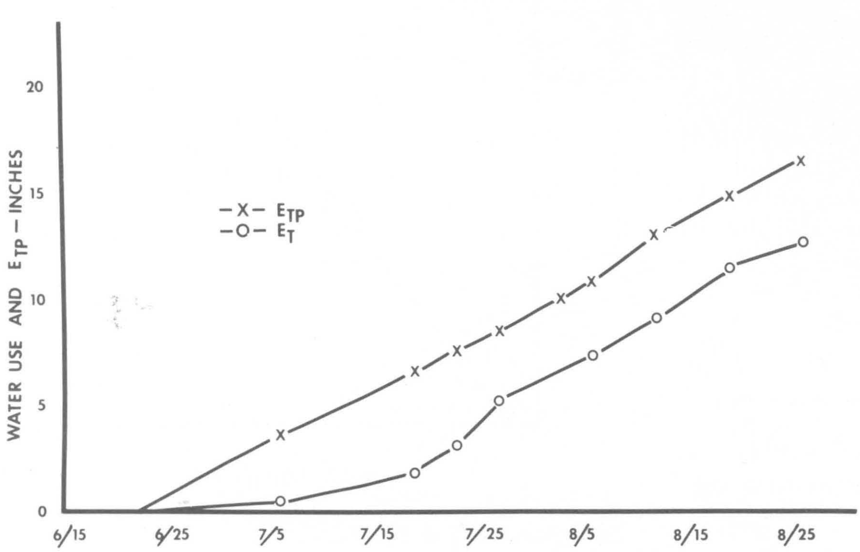

Figure 11. Average accumulative moisture use by cotton irrigated two and three times and potential evapotranspiration (ETp) as determined from climatic data, 1976.

GRAIN SORGHUM

Summary

Sorghum yields were a linear function of applied water and water use. Irrigation with 10 to 14 inches, 3 to 5 inches per irrigation, during the reproductive stages of plant growth increased yields from about 3,000 to 6,600 pounds per acre. The average production of grain sorghum was about 304 pounds per inch of water used. An average of 24 inches of water was required to produce about 6,600 pounds of grains sorghum per acre. Grain sorghum planted two rows per bed produced about 4 percent higher yield than single-row grain sorghum.

Methods and Materials

Studies to determine the water use requirements and water use efficiency of grain sorghum were conducted at the Munday Station during 1976, 1977, and 1978. The soil is a Miles fine sandy loam. The treatments were arranged in a split-plot design with main plots irrigation treatments and subplots row configurations. Planting dates in 1976, 1977, and 1978 were May 10, May 21, and May 24, respectively.

Plots were sixteen 40-inch rows wide by 125 feet long. Plots received 125 N/A and 80 pounds of P_2O_5 per acre each year. Irrigation water was applied with gated pipe and sprinklers in 1976 and with sprinklers in 1977 and 1978. Water was metered onto all plots. Plant populations were approximately the same regardless of row configuration and moisture level.

Treatments were irrigated when varying amounts of soil moisture were depleted and/or by growth stage. Moisture depletions were based on the estimated crop water use. Treatments are described in Tables 4 and 5.

Crop water use was estimated using Jensen's (6) method of determining potential evapotranspiration. The water use was then estimated by adjusting the potential evapotranspiration with the percentage of ground covered by the crop canopy. Adjustments were also made for rainfall. In 1978 on August 2 and 3, more than 8 inches of rainfall was received. The rainfall figures for the large rain were adjusted by treatments to correct for estimated runoff on August 2 and 3.

Soil moisture data were determined by gravimetric sampling of the surface foot and by neutron scattering at

TABLE 4. IRRIGATION TREATMENTS FOR GRAIN SORGHUM, 1976, MUNDAY, TEXAS

Relative irrigation level	Irrigation level description	Number of irrigations
Wet	Irrigated when ⅓ of available soil moisture depleted from top 2 feet; applied 1 inch water with sprinkler	11
Medium (sprinkler)	Irrigated when ½ of available soil moisture depleted from top 2 feet; applied 1.5 inches water with sprinklers	7
Dry (sprinkler)	Irrigated when ⅔ of available soil moisture depleted from top 2 feet; applied 2.0 inches water with sprinklers	5
Medium (furrow)	Irrigated when ½ of available soil moisture depleted from top 2 feet; applied 2.0 inches with gated pipe	7
Dry (furrow)	Irrigated when ⅔ of available soil moisture depleted from top 2 feet; applied 2.5 inches with gated pipe	5
Non-irrigated	Received only rainfall during growing season	0

TABLE 5. IRRIGATION TREATMENTS FOR GRAIN SORGHUM, 1977 AND 1978, MUNDAY, TEXAS

Relative irrigation level	Irrigation level description	Number of irrigations	
		1977	1978
Wet	Applied 100% of water use when estimated water use was 1.0 inch	14	10
Medium	Applied 75% of water use when estimated water use was 2.0 inches	6	6
Dry	Applied 50% of water use during each of following stages a) emergence through vegetative b) vegetative through early boot-bloom c) early boot-bloom through soft dough	3	4
Very dry	Applied 100% of water use at early boot-bloom, not to exceed 3.0 inches	1	2
Non-irrigated	Received only rainfall during growing season	0	0

other depths to 5 feet. Water use estimates using soil moisture depletion are subject to errors due to unaccountable losses due to runoff and subsurface drainage or percolation. In most instances there was no runoff from plots in these studies. However, on the above occasion of unusually heavy rainfall on August 2 and 3, it was necessary to make an estimate of runoff.

Most of the studies reported in this publication were conducted on the Miles fine sandy loam, Abilene clay loam and related type soils. These soils have compacted on slowly permeable subsoils or hardpans at soil depth of about 10-15 inches (5). Because of the physical properties of these soils, deep percolation was considered negligible. In the Rolling Plains in 1977 (Knox County) Wendt et al. (9) reported that deep percolation was negligible on a Miles loamy fine sand. These findings would suggest that depletion technique would give reliable estimates of soil moisture use on many soils in the Rolling Plains. Errors on water use estimates using depletion technique by crops over the entire season would probably be small.

TABLE 6. GRAIN SORGHUM YIELD, 1976, MUNDAY, TEXAS

Relative irrigation level	Yield, pounds/acre		
	Single	Double	Mean*
Wet	6556	6615	6586a
Medium (sprinkler)	6064	6247	6280ab
Dry (sprinkler)	6010	6315	6180ab
Medium (furrow)	5989	6496	6152ab
Dry (furrow)	5816	6350	6032b
Non-irrigated	3208	3376	3292c
Mean*	5607a	5900b	

*Means not followed by the same letter are significantly different at the 5% probability level.

Row configurations were single and double rows per bed. Double rows were planted 10 inches apart. Both configurations were seeded to produce approximately the same plant population per acre. The desired plant density was six plants per foot of bed.

Sprinkler irrigated plots had sprinkler spacings of 40 feet in 1976 and 30 feet in 1977 and 1978. Yield and plant growth data were collected from the second, third, and fourth rows from the plot centers.

Results

Yield data from 1976, 1977, and 1978 are given in Tables 6 and 7. Yields were highly correlated with available water from irrigation and rainfall. Total water use and water use efficiencies from irrigation treatments in 1976, 1977, and 1978 are given in Tables 8, 9, and 10, respectively.

Summer rainfall significantly influenced sorghum yields, especially yields of non-irrigated sorghum in 1976 and 1978. In 1976 (Figure 12) frequent precipitation occurred from boot through bloom stages. Dryland yields in 1976 averaged 3,300 pounds per acre (Table 6). In 1977 non-irrigated sorghum produced only 1,600 pounds per acre because less rainfall was received during the reproductive stages of plant growth. The 1978 crop year was characterized by low rainfall until after the sorghum's normal blooming date (Figure 12). However, over 8 inches of rainfall was received on August 2 and 3, causing non-irrigated sorghum to produce a late crop of 4,200 pounds per acre. Test weights of non-irrigated grain were less in 1978.

Yields were a linear function of applied water (Figure 13). The contrasting rainfall conditions during the 3 years complicated the relationship shown in Figure 13. Dryland grain sorghum ranged from about 1,600

TABLE 7. GRAIN SORGHUM YIELD, 1977 AND 1978, MUNDAY, TEXAS

Relative irrigation level	1977 Yield pounds/acre			1978 Yield pounds/acre		
	Single	Double	Mean*	Single	Double	Mean*
Wet	5546	5813	5680a	5584	5842	5713a
Medium	5027	5463	5245a	5638	5831	5735a
Dry	4427	4382	4405b	5003	5590	5297ab
Very dry	3428	2975	3202c	4356	4644	4500bc
Non-irrigated	1715	1417	1566d	3975	4417	4196c
Mean*	4029	4012		4911d	5265e	

*Means not followed by the same letter are significantly different at the 5% probability level for each year, respectively.

TABLE 8. GRAIN SORGHUM WATER USE AND WATER USE EFFICIENCY, 1976, MUNDAY, TEXAS

Relative irrigation level	Irrigation water applied, inches	Water use, inches		Water use efficiency, pounds/inch	
		Single	Double	Single	Double
Wet	12.9	23.3	22.8	286	291
Medium (sprinkler)	12.1	22.6	22.2	268	282
Dry (sprinkler)	10.5	21.5	21.0	280	301
Medium (furrow)	14.0	23.8	24.3	251	268
Dry (furrow)	12.0	22.5	22.8	259	279
Non-irrigated	0	10.8	11.2	297	303

TABLE 9. GRAIN SORGHUM WATER USE FOR 1977 AND 1978, MUNDAY, TEXAS

Relative irrigation level	Irrigation water applied, inches	Water use, inches	
		Single	Double
	1977		
Wet	14.9	22.2	22.8
Medium	9.8	19.1	19.3
Dry	6.0	16.2	16.0
Very dry	3.0	13.6	13.2
Non-irrigated	0	11.1	11.1
	1978		
Wet	12.1	21.4	21.9
Medium	10.0	21.2	20.9
Dry	8.0	20.9	21.0
Very dry	6.0	17.2	17.0
Non-irrigated	0	14.6	15.5

TABLE 10. GRAIN SORGHUM WATER USE EFFICIENCY FOR 1977 AND 1978, MUNDAY, TEXAS

Relative irrigation level	Water use efficiency, pounds/inch			
	1977		1978	
	Single	Double	Single	Double
Wet	250	255	261	267
Medium	263	283	266	279
Dry	274	275	239	266
Very dry	252	222	253	273
Non-irrigated	155	130	272	285

pounds in 1977 to 4,200 pounds per acre in 1978. The average dryland production was about 3,000 pounds per acre. On the average, irrigation increased yields from 3,000 to about 6,600 pounds per acre. The average production per inch of applied water was about 240 pounds per acre (Figure 13). It appears that maximum yields for Rolling Plains climatic conditions are obtained when 10 to 14 inches of supplemental irrigation water are applied during the growing season. Water should be applied during the critical growth periods for maximum effectiveness.

Relationship between yield and water use (Figure 14) indicated that despite summer rainfall water is the dominant factor which influences yields. In 1977, a dry year, the relationship between yield and water use indicated that about 5 inches of water was needed before any yield was produced. However, (Tables 8 and 10) the average sorghum produced per inch of water was 281, 237, and 266 pounds in 1976, 1977, and 1978, respectively. The lower average production per inch of water in 1977 was due to low production by dryland sorghum. Dryland single and double row sorghum in 1977 produced only 155 and 130 pounds per inch of water, respectively.

In 1976 double rows per bed consistently out yielded single rows per bed with an average increase of 5 percent. In 1977 double rows were best on the more

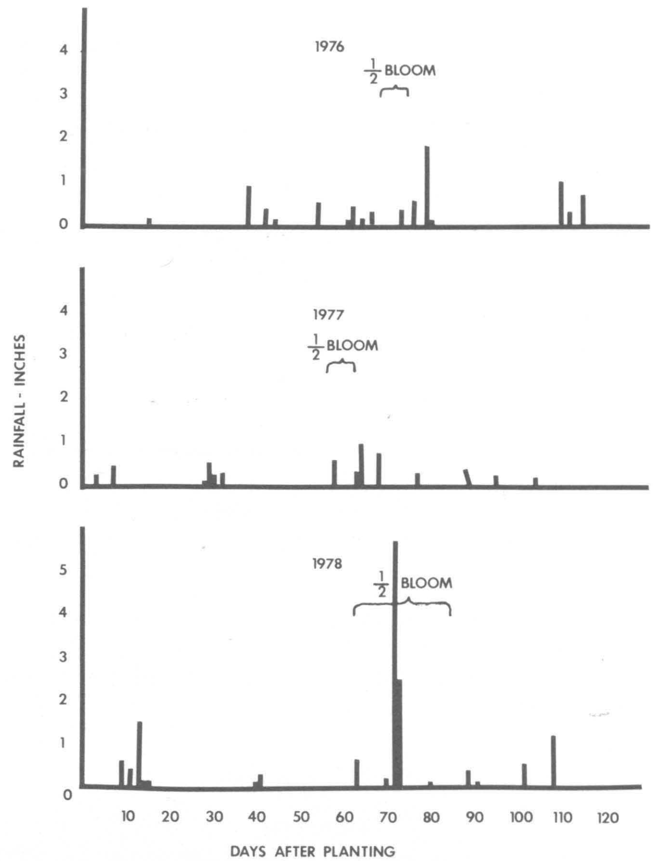

Figure 12. The rainfall pattern and amounts with respect to days after planting for sorghum in 1976, 1977 and 1978. The range in time of ½ bloom stage of variously irrigated sorghum is indicated.

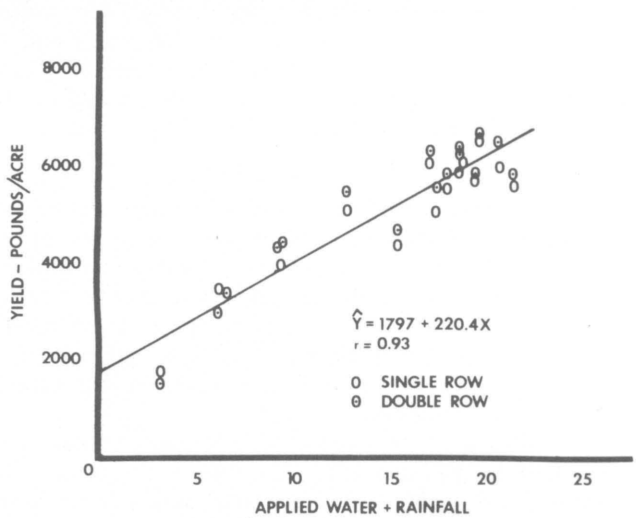

Figure 13. Relationship between yields of sorghum and applied water plus rainfall during period of 40 to 120 days after planting.

heavily irrigated treatments, while in 1978 double rows were again higher yielding by 7 percent. Double rows per bed can give yield increases in some years, but the magnitude of this increase in the Rolling Plains appears to be small.

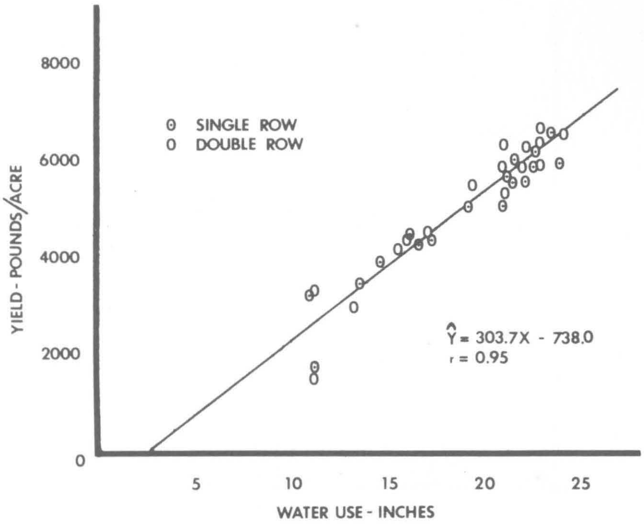

Figure 14. Relationship between yields of sorghum and water use.

An advantage of double rows per bed over single rows per bed is the shading effect on weeds. Observations indicate that mid- to late-season weed growth was considerably less on plots with double rows per bed.

SMALL GRAINS

Summary

The water use-wheat yield relationship in 1977 showed that about 15 inches of water is required for production of a 50-bushel crop. Available moisture needed, during April and May, to produce a 40- to 50-bushel per acre crop of wheat is about 0.20 to 0.25 inch per day. Rainfall from September through May which could influence wheat yields averages about 17 and 22 inches at Chillicothe and Iowa Park, respectively. These data emphasize that irrigation often is not needed for the production of 30 to 50 bushels of wheat per acre.

Methods and Materials

Moisture use by dryland and irrigated wheat following different cropping and fertility treatments was evaluated for 1976, 1977, and 1978 crop years. The dryland and irrigated wheat experiments at Chillicothe were in randomized block design consisting of four replications. Response of wheat in 1976 and 1977 to irrigation was small or insignificant. In 1978 the wheat in that experiment was not irrigated.

Studies were conducted with wheat and barley at Iowa Park in 1977 and 1978. The roles of furrow and flat irrigation on yield and water use and salinity were compared. Because of timely rains, the crops were not irrigated in 1977. The wheat was planted in December and November in 1976 and 1977, respectively. Because of lack of September and October rainfall the fields were pre-irrigated in October 1977 and wheat and barley planted in November 1977. The small grain crops were irrigated on April 14 and 28, 1978.

Moisture use by wheat and barley was evaluated at Chillicothe and Iowa Park for crop years 1977 and 1978. The surface foot of soil was gravimetrically determined. Soil moisture at depths of 1 to 4 feet was determined at 6-inch intervals by neutron scattering technique.

Yields of wheat and barley were obtained by harvesting a strip in each plot with a self-propelled combine. Yields were converted to bushels per acre, and yields and test weights as influenced by treatment were measured.

The relationship between total moisture use and small grain yields at Chillicothe and Iowa Park was calculated. The estimated relationship between moisture use in inches per day during April and May (considered as critical to yield) and yield was determined for wheat. Barley yields were converted to 60 pounds per bushel for these calculations.

LAI measurements of wheat obtained with Lambda leaf area meter were made in 1977 and 1978. The relationship between maximum LAI and yields of wheat was calculated.

Results

Wheat yields in the Rolling Plains are often limited by factors other than moisture. For example, experimental results in 1975-76 and 1976-77 at Chillicothe indicated that irrigation did not markedly influence wheat yields (unpublished data). However, the 1977-78 small grain crop year was characterized by a deficient supply of water at planting time in 1977 and in the early spring of 1978. Because moisture was deficient, it was possible to determine the relationship between yield and water use from results obtained at Chillicothe and Iowa Park (Figure 15). Yields were a highly significant linear function of water in the range of 7 to 15 inches. This relationship indicated that about 7 inches of water was required before the small grain produced any crop. Every inch of water above 7 inches produced 6 bushels (Figure 15).

The relationship between yields in bushel per acre and moisture use in inches per day by small grain at Chillicothe and Iowa Park in 1976-77 and 1977-78 in April and May was highly significant and linear. The available moisture needed during April and May for a 40- to 50-bushel-per-acre wheat crop is about 0.20 to 0.25 inch per day (Figure 16). The relationship between maximum LAI during this critical stage and wheat yields is also linear and highly significant (Figure 17).

About 15 inches of water is required to produce a 50-bushel crop of wheat in the Rolling Plains (Figure 15). Data from the experiment stations at Chillicothe and Iowa Park (Table 11) indicate that average rainfall from September through May which could influence wheat yields was about 17 and 22 inches, respectively. These data emphasize why irrigation is often not needed in the Rolling Plains for production of 30 to 50 bushels of wheat per acre. This is particularly true of the area in the Rolling Plains where more than 15 inches occur during the wheat production season. However, in 1977-78 rainfall for the period from September through May at Chillicothe and Iowa Park averaged only 10.5 inches. At Chillicothe about 3.50 inches of this rainfall occurred after May 18. The result was that non-irrigated wheat produced only 10 to 20 bushels per acre in 1977-78.

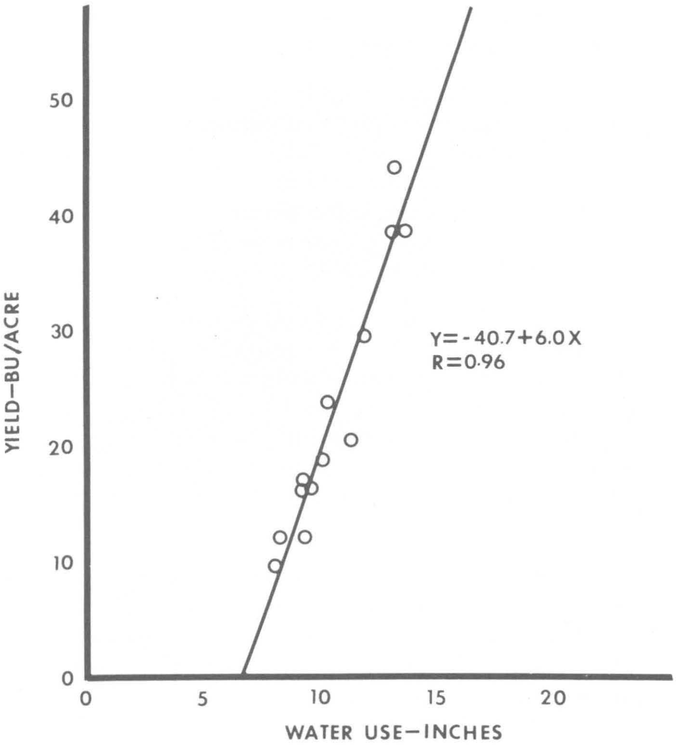

Figure 15. Relationship between yields of small grain in bushels/acre and water use in 1977-78.

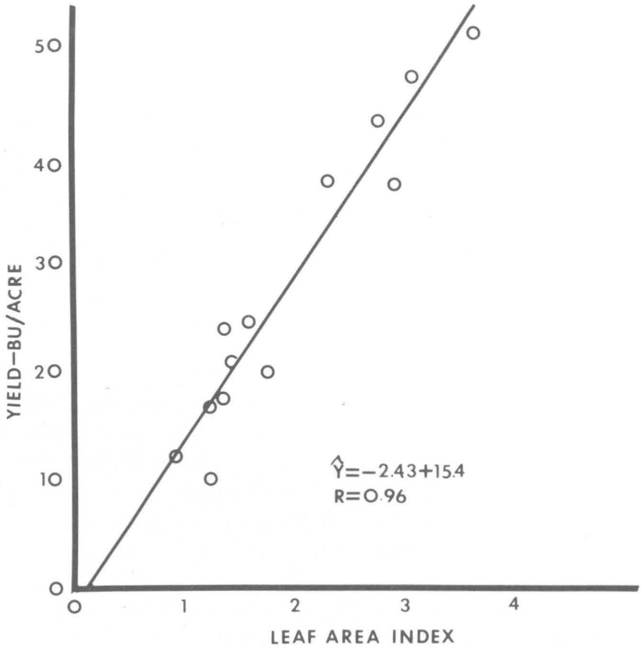

Figure 17. Relationship between yields of wheat in bushels/acre in 1976-77 and 1977-78 and maximum leaf area indices (LAI) during critical growth stages of April and May.

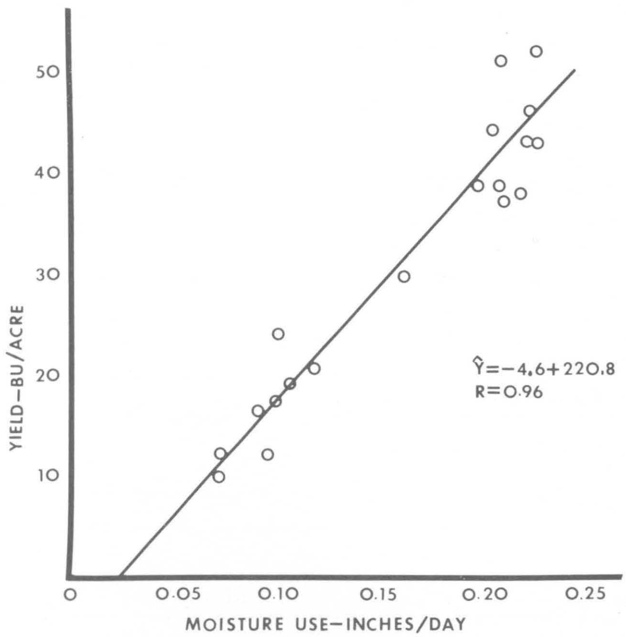

Figure 16. Relationship between yields of small grain in bushels/acre and water use in inches/day in 1976-77 and 1977-78.

TABLE 11. AVERAGE MONTHLY RAINFALL AT EXPERIMENT STATIONS AT CHILLICOTHE, IOWA PARK, AND MUNDAY

Months	Chillicothe, inches[a]	Iowa Park, inches[b]	Munday, inches[c]
January	0.78	1.11	0.95
February	0.91	1.41	1.13
March	1.35	1.89	1.23
April	2.23	2.78	2.43
May	3.83	4.50	3.76
June	3.09	3.11	2.85
July	2.16	2.43	2.33
August	2.05	2.50	2.05
September	2.99	3.45	2.93
October	2.81	3.36	2.52
November	1.19	1.52	1.29
December	1.00	1.58	1.17
TOTAL	24.39	29.64	24.64

[a]72-year average
[b]51-year average
[c]30-year average.

Finally, these data suggest why irrigation water is often not needed in the production of small grain in the Rolling Plains.

The knowledge that rainfall is often adequate to produce maximum small grain yields in the Wichita Valley could be used to reduce soil salinity on soils with moderate to high salinity. Soil salinity created by irrigating with saline water could be reduced by (a) planting salt tolerant barley and (b) following the barley crop with a fallow period until the next spring. The amount of salts leached below the effective root zone by this practice would be influenced by September and October rainfall (Table 11) and the condition or permeability of the soil at the time of these rains.

POTATOES

Summary

Potato production was a linear function of applied water and water use. Yields of large potatoes (> 3.0 inches) were a hyperbolic function of water use. Frequent irrigations and maintenance of low soil moisture suction were needed to produce large potatoes and high yields. Red LaSoda was more efficient in water use than Norchip, producing more large potatoes and higher yields. Red LaSoda produced 250 hundredweights per acre (cwt/acre) with 17 to 18 inches of water.

Methods and Materials

Irish potato production in the Texas Rolling Plains is concentrated in the Knox County area with 1,000 to 1,300 acres in production yearly. The majority of the crop is sold as fresh market or chippers. Data were not available on water use requirements of potatoes in the Texas Rolling Plains prior to 1976 (1).

A study was set up at the Texas A&M Vegetable Research Station in 1976 to determine the water use requirements and the yield and growth characteristics of potatoes grown under different water regimes. Valid data were collected from these studies in 1976 and 1978. The variety Red LaSoda was used in 1976; Red LaSoda and Norchip were used in 1978.

Plots were sixteen 40-inch rows wide by 125 feet long. Irrigation was with gated pipe or sprinklers in 1976 and with sprinklers only in 1978. The plots were planted with a plot planter to a desired "in row" spacing of 9-10 inches. Seed piece size was approximately 1½ to 2 ounces each. Final plant spacing was approximately 15 inches in 1976 and 10 inches in 1978.

Crop water use was estimated using Jensen's (7) method of determining the potential evapotranspiration. The potential evapotranspiration was adjusted using the percentage of ground covered by the crop canopy and the rainfall between irrigations. Depending upon treatments (Tables 12 and 13), potatoes were irrigated on the basis of soil moisture conditions or estimated evapotranspiration.

Plots received 100 to 120 pounds P_2O_5 and 150 pounds N/A each year. All plots were treated with disulfoton (DiSyston) at 3 pounds active ingredient per acre. Yield data were collected from two 33-foot row sections in each plot.

TABLE 12. IRRIGATION TREATMENTS FOR POTATOES, 1976, MUNDAY, TEXAS

Relative irrigation level	Irrigation level description	Number of irrigations
Very wet	Irrigated when tensiometer readings at 6 and 12 inches averaged .15 atmosphere suction; applied .75 inches water with sprinklers	12
Wet	Irrigated when 33% of available soil moisture was depleted from 2-foot root zone; applied 1.00 inch water with sprinklers	6
Medium (sprinkler)	Irrigated when 50% of available soil moisture was depleted from 2-foot root zone; applied 1.50 inches water with sprinklers	4
Medium (furrow)	Irrigated when 50% of available soil moisture depleted from 2-foot root zone; applied 2.00 inches with gated pipe	4
Dry (sprinkler)	Irrigated when 67% of available soil moisture depleted from 2-foot root zone; applied 2.00 inches with sprinklers	3
Dry (furrow)	Irrigated when 67% available soil moisture depleted from 2-foot root zone; applied 2.50 inches with gated pipe	3
Non-irrigated	Received only rainfall during growing season	0

TABLE 13. IRRIGATION TREATMENTS FOR POTATOES, 1978, MUNDAY, TEXAS

Relative irrigation level	Irrigation level description	Number of irrigations
Very wet	Irrigated when tensiometer readings at 6 and 12 inches average .15 atmosphere suction; applied .75 inch water with sprinklers	16
Wet	Irrigated every 7 days; applied 100% of estimated evapotranspiration	7
Medium	Irrigated every 7 days; applied 75% of estimated evapotranspiration	7
Dry	Irrigated every 10-11 days; applied 75% of estimated evapotranspiration	6
Very dry	Irrigated every 10-11 days; applied 50% of estimated evapotranspiration	6
Non-irrigated	Received only rainfall during growing season	0

Soil moisture readings were obtained by gravimetric sampling of the surface foot and by neutron scattering at other depths to 5 feet.

Irrigation treatments varied between years; however, two treatments were identical each year allowing comparison of treatments over years.

Results

Potatoes, variety Red LaSoda in 1976 and 1978 and Norchip in 1978, were grown under varying irrigation schedules to determine their water use requirements in the Texas Rolling Plains. Yields and water use efficiency of Red LaSoda and Norchip in 1976 and 1978 are shown in Tables 14, 15, and 16. Yield was linearly correlated with applied water regardless of year or variety (Figures 18 and 19).

The yield increases from added irrigation water are the result of an increased percentage of tubers in the "greater than 3.0 inch diameter" category (Tables 17 and 18). As treatments became drier, the majority of weight shifted to the smaller size categories. The Red LaSodas produced under dryland in 1978 had almost 75 percent of the yield in the "less than 1⅞ inch diameter" category, while only 15 percent of the wettest treatment was less than 1⅞ inch diameter (Table 19).

The dramatic effect of a slight change in water availability and use on potato yields is shown in Figure 20. The yields of tubers over 3.0 inches in diameter are hyperbolic functions of water use. Short delays in applying an irrigation can thus result in rather large yield decreases, especially late in the growing season when water requirements are high. Similar effects would

TABLE 14. POTATO YIELD OF RED LASODA, WATER USE, AND WATER USE EFFICIENCY, MUNDAY, TEXAS, 1976

Relative irrigation level	Yield #1 potatoes, cwt/acre[1]	Yield, total marketable, cwt/acre	Irrigation water applied, inches	Total water use, inches[2]	Water use efficiency,[3] cwt/inch
Very wet	228.8c	244.9c	8.7	14.6	16.8a
Wet	185.3bc	195.0bc	6.4	12.9	15.1a
Medium (sprinkler)	163.5b	173.5b	6.0	11.5	15.1a
Medium (furrow)	173.6b	181.1b	7.0	13.6	13.3a
Dry (sprinkler)	171.9b	180.7b	6.3	11.3	16.1a
Dry (furrow)	147.8b	156.9b	6.7	13.4	11.7a
Non-irrigated	83.4a	94.3a	0	7.1	13.3a

[1]Includes only those potatoes greater than 1⅞ inches in diameter.

[2]Includes irrigation water applied, rainfall, used stored soil moisture, and drainage.

[3]Calculated using total marketable yield and total water use. Values followed by the same letter do not differ significantly at the 5% level.

TABLE 15. POTATO VARIETY RED LASODA YIELD, WATER USE, AND WATER USE EFFICIENCY, MUNDAY, TEXAS, 1978

Relative irrigation level	Yield #1 potatoes, cwt/acre	Yield, total marketable, cwt/acre	Irrigation water applied, inches	Total water use, inches	Water use efficiency, cwt/inch
Very wet	247.2a	279.5a	13.8	18.2	15.4
Wet	156.9b	196.5b	10.7	15.3	12.8
Medium	136.9bc	185.1b	8.2	13.0	14.2
Dry	89.7cd	138.8c	7.8	13.1	10.6
Very dry	71.4d	124.1c	5.6	10.8	11.5
Non-irrigated	8.7e	34.6d	0	6.0	5.8

TABLE 16. POTATO VARIETY NORCHIP, YIELD, WATER USE, AND WATER USE EFFICIENCY, MUNDAY, TEXAS, 1978

Relative irrigation level	Yield #1 potatoes, cwt/acre	Yield, total marketable, cwt/acre	Irrigation water applied, inches	Total water use, inches	Water use efficiency, cwt/inch
Very wet	143.9a	198.5a	13.8	17.6	11.3
Wet	81.5b	158.9b	10.7	15.1	10.5
Medium	79.4b	141.1bc	8.2	12.5	11.3
Dry	50.5bc	114.6cd	7.8	12.7	9.0
Very dry	32.9bc	94.4d	5.6	10.5	9.0
Non-irrigated	7.8c	43.2e	0	6.0	14.4

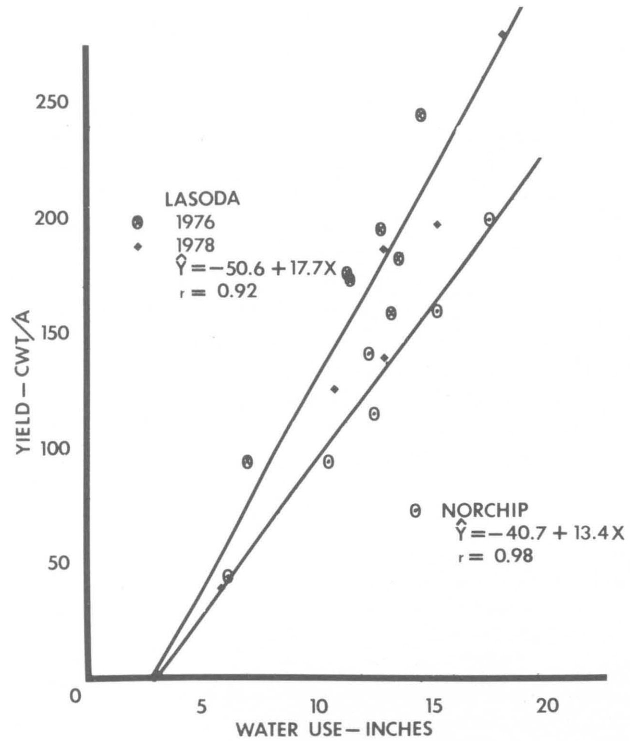

Figure 18. Relationship between yield in hundredweights/acre of No. 1 Red La Soda and Norchip and water use.

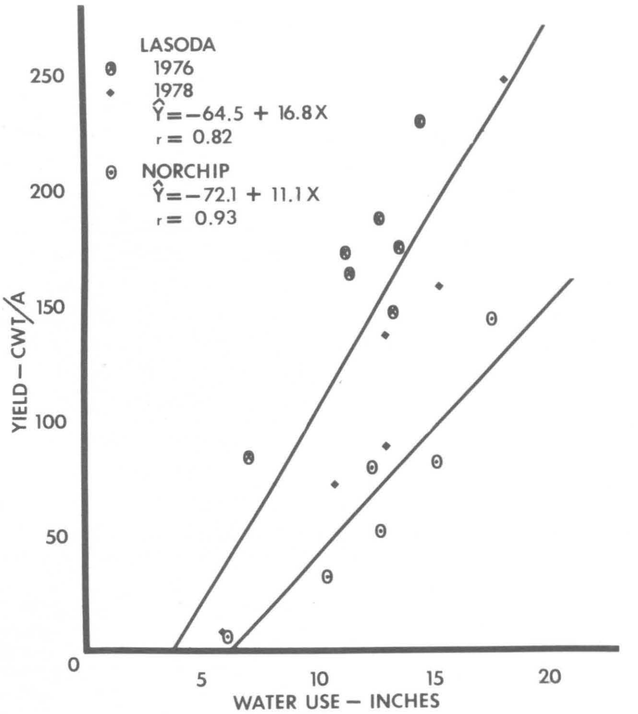

Figure 19. Relation between total yields in hundredweights/acre of Red LaSoda and Norchip and water use.

result from a poor job of applying or distributing irrigation water. Stress or climatic conditions (years) can cause marked differences in the response to water (Figure 20). The variety Red LaSoda produced more large potatoes in 1976 with less water than in 1978.

The variety Norchip (Figure 20) is much less efficient in producing large potatoes than the Red LaSoda, explaining why Red LaSoda uses water more efficiently than the variety Norchip. A comparison of the tuber production by Red LaSoda and Norchip in Tables 17 and 18 shows that the total numbers of tubers of Red LaSoda and Norchip under the different treatments were almost identical, but the LaSoda had considerably more 3.0 inch-diameter tubers than Norchip.

The water use efficiency of the Red LaSoda is considerably higher than that of Norchip even though total water use was slightly higher for Red LaSoda in 1978. The greater water use efficiency is due to the higher yields produced by Red LaSoda.

A comparison of furrow and sprinkler irrigation treatments for Red LaSoda in 1976 indicated no significant yield or water use efficiency differences between methods of applications. Even so, it is worthy to note

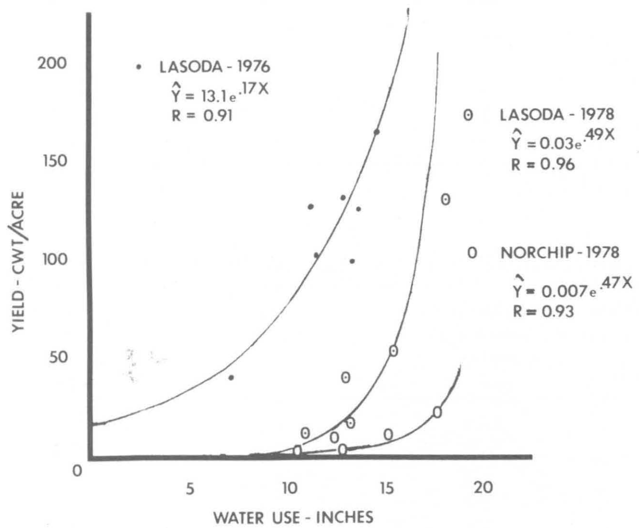

Figure 20. Relationship between yields in hundredweights/acre of large potatoes (≥ 3.0″ diameter) and water use.

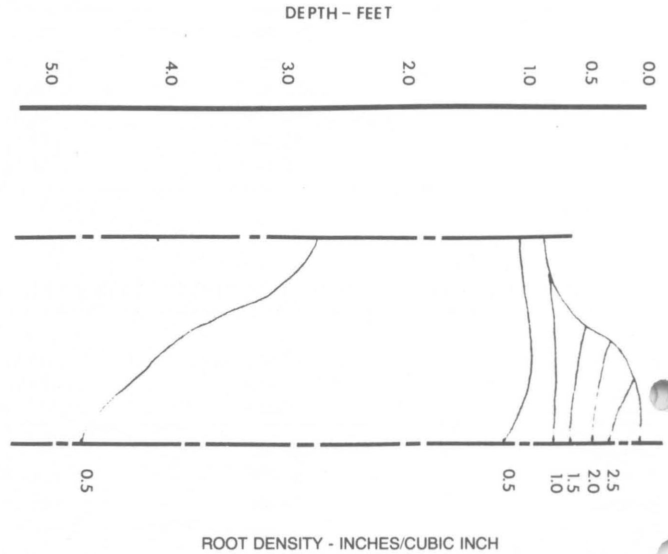

Figure 21. Bed cross section showing rooting density by frequently irrigated Red La Soda potatoes, 1976.

TABLE 17. NUMBER OF RED LASODA TUBERS HARVESTED, MUNDAY, TEXAS, 1978

Relative irrigation level	Number of tubers greater than 3.0″ per acre	Number of tubers greater than 1⅞″ but less than 3.0″ per acre	Number of tubers less than 1⅞″ per acre	Total number of tubers per acre
Very wet	29,502	42,174	23,562	95,238
Wet	12,870	41,184	27,324	81,378
Medium	9,702	37,026	32,076	78,804
Dry	3,960	29,502	39,402	72,864
Very dry	2,772	25,334	36,828	64,944
Non-irrigated	0	3,762	20,790	24,552

TABLE 18. NUMBER OF NORCHIP TUBERS HARVESTED, MUNDAY, TEXAS, 1978

Relative irrigation level	Number of tubers greater than 3.0″ per acre	Number of tubers greater than 1⅞″ but less than 3.0″ per acre	Number of tubers less than 1⅞″ per acre	Total number of tubers per acre
Very wet	5,940	47,718	36,234	89,892
Wet	2,376	33,264	59,202	94,842
Medium	2,772	32,274	48,312	83,358
Dry	396	23,364	46,728	70,488
Very dry	198	16,236	52,074	68,508
Non-irrigated	0	3,960	31,482	35,442

TABLE 19. PERCENTAGE OF TUBER WEIGHT BY GRADE SIZE, MUNDAY, TEXAS, 1978

Relative irrigation level		% by weight greater than 3.0″	% by weight greater than 1⅞″ but less than 3.0″	% by weight less than 1⅞″
Very wet	LaSoda	46.6	41.9	15.5
Wet		27.2	52.6	20.2
Medium		21.5	52.4	26.1
Dry		11.9	52.7	35.4
Very dry		8.2	49.4	42.4
Non-irrigated		0.8	24.3	74.9
Very wet	Norchip	10.8	61.7	27.5
Wet		5.4	46.6	48.0
Medium		6.9	49.4	43.7
Dry		1.0	43.0	56.0
Very dry		0.8	34.0	65.2
Non-irrigated		0.0	18.1	81.9

that the treatments watered with sprinklers had a higher water use efficiency than their treatment counterparts which were watered with gated pipe. This is generally expected.

The 1978 Red LaSoda data (Table 15) indicate that irrigation intervals of greater than 7 days can cause significant yield reduction. However, decreasing the water applied by 25 percent and keeping a 7-day irrigation interval only decreased yields slightly. This shows that the timing and the amount of water applied are very critical in potato production.

Potatoes on this soil have a shallow root system (Figure 21). This is somewhat typical of some vegetable crops. However, the rooting density shown in Figure 21 may have been created in part by a compacted layer at the 10- to 15-inch soil depth. This means potatoes exploited a shallow reservoir on this soil. For high yields the shallow reservoir required frequent replenishment by irrigation or rainfall.

SWEET CORN

Summary

Sweet corn yields were a linear function of applied water and water use in 1977. However, rainfall was adequate to produce maximum yields in 1978. In the eastern part of the Rolling Plains it is expected that May and June rainfall often will minimize the effect of irrigation on vegetable crops with short growing seasons such as sweet corn.

Methods and Materials

A drip irrigation system was used to study the response of sweet corn to different levels of drip irrigation in 1977 and 1978. Levels of drip irrigation which were based on different levels of potential evapotranspiration are indicated in Table 20. Potential evapotranspiration in inches was estimated as 0.6 to 0.7 Class A Weather Bureau pan. Pan evaporation was measured at the Texas Agricultural Experiment Station at Iowa Park. Drip irrigation levels were applied between bed and furrow with Submatic emitters spaced 2 feet apart. Plots were four rows wide and 50 feet in length; each treatment was replicated three times. The amounts of water applied to different treatments were automatically controlled with pressure regulators and timers which controlled cut-off solenoids. Moisture use by sweet corn on different treatments was determined by neutron scattering techniques and gravimetric sampling. Salinity of soil was determined initially and after harvesting of sweet corn in 1977 and 1978. Yield of sweet corn was evaluated by harvesting and counting ears. The relationships between yield and water applied and water use were determined in 1977. In 1977 and 1978, attempts were made to grow crops of squash and sweet pepper, respectively. Problems with germination of squash and early growth of peppers were encountered.

Results

Yields of sweet corn in 1977 (Table 20) were excellent, and a linear function of applied water and water use as shown in Figures 22 and 23. An attempt to grow a second crop in 1977 (squash) was unsuccessful because the latter did not germinate. Dry weather in late spring and summer resulted in detrimental salt accumulations in this soil (Yahola fine sandy loam). The level of salinity was high enough to prevent germination on all treatments, including the dry treatments. Actually, the sweet corn on all plots, including the dry treatment, had to be irrigated at planting time. The average soil salinity by depth prior to initiation of the experiment and after irrigation in 1977 and salinity conditions at different depths and treatments after sweet corn in 1977 are shown in Table 21.

In 1978 (Table 22) timely rains minimized the response of sweet corn to irrigation. Variability between

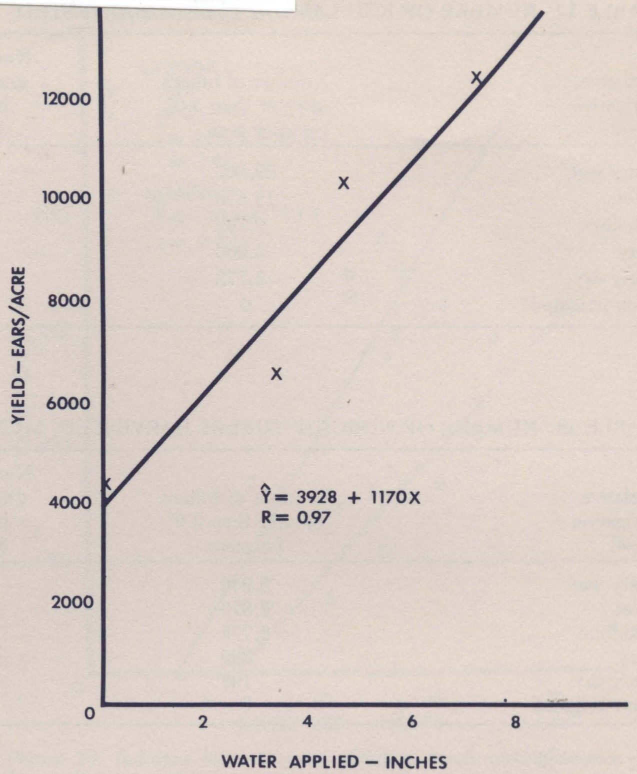

Figure 22. Relationship between yield of sweet corn in ears/acre and applied water in 1977.

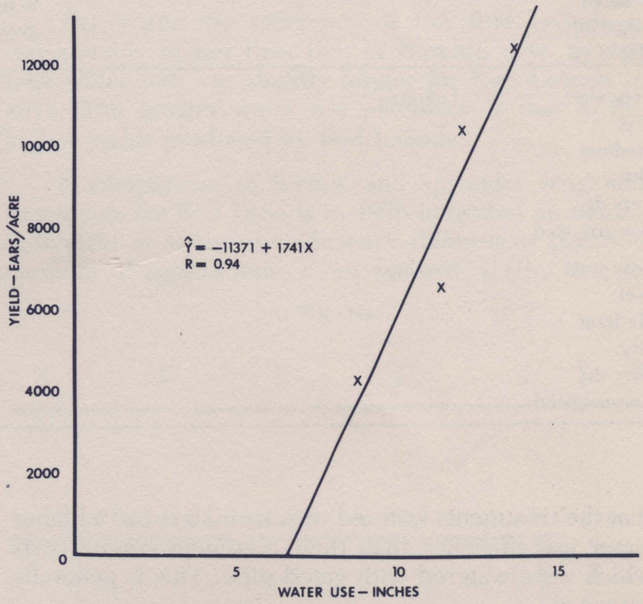

Figure 23. Relationship between water use and sweet corn yields under drip irrigation treatments, 1977.

TABLE 20. YIELDS AND WATER USE DATA BY SWEET CORN AS INFLUENCED BY DRIP IRRIGATION, 1977

Treatment-level of potential evapotranspiration	Yield, ears/acre	Water use, inches	Ears/in of H_2O
0*	4,300	8.8	490
50%*	6,600	11.3	580
100%*	10,400	11.9	875
150%*	12,500	13.6	920
Sign	0.01		

*All treatments were irrigated after planting in 1977.

plots was greater in 1978 than 1977. In 1978 an attempt to grow a second crop of peppers was unsuccessful. Soil salinity data in Table 23 indicate that the salinity levels were not high enough prior to the sweet corn crop in April and just after planting of the pepper crop in August to cause the crop failure. Residual herbicide from the sweet corn crop was believed responsible for loss of the pepper crop.

Shape of row, amount of water applied at each irrigation, and subsurface drip irrigation rather than surface drip irrigation might reduce salinity of the soil surface. Further studies are needed to determine the roles of these management practices on yields and soil productivity. This method of irrigation would probably be excellent for vegetable and pecan production. However, use of drip irrigation with the salty water from Lake Kemp will require that a leaching fraction be applied to keep the soil salinity in the effective root zone below hazardous levels.

TABLE 21. AVERAGE SOIL SALINITY AT DIFFERENT DEPTHS PRIOR TO AND AFTER IRRIGATION AND GROWTH OF CORN CROP, 1977

Depth inches	Prior to irrigation	Soil Salinity level of drip irrigation (PE)[a] 0	50%	100%	150%
		mmhos/cm[b]			
0-6	1.8	6.5	6.1	11.5	7.9
6-12	2.1	4.0	4.6	5.7	5.1
12-24	2.0	3.1	5.3	5.2	4.0
24-36	1.9	3.5	4.3	4.7	4.1
36-48	2.6	-	-	-	-
48-60	3.3	-	-	-	-

[a]Estimated level of potential evapotranspiration.
[b]Conductivity of solution extracted from saturated soil paste.

TABLE 22. YIELDS AND WATER USE DATA BY SWEET CORN AS INFLUENCED BY DRIP IRRIGATION, 1978

Treatment level of potential evapotranspiration	Yield ears/acre[a]	Water use, inches	Ears/in of H_20
0	8800	7.3	1200
50%	10500	11.1	950
100%	9700	13.1	740
150%	11350	16.2	690

[a]Yields were not significantly influenced by treatments in 1978.

TABLE 23. SOIL SALINITY AS INFLUENCED BY DRIP IRRIGATION TREATMENT, 1978

Depth, inches	0%		Level of potential evapotranspiration 50%		100%		150%	
	mmhos/cm*							
	4/11	8/11	4/11	8/11	4/11	8/11	4/11	8/11
0-6	1.8	1.1	2.5	2.6	2.7	2.6	2.0	1.8
6-12	1.7	1.7	2.0	4.3	2.0	5.2	2.0	3.0
12-24	2.5	3.3	2.7	5.6	2.5	4.5	3.2	3.7
24-36	2.4	2.8	2.7	4.7	2.7	2.7	3.4	4.2
36-48	2.6	2.4	3.2	3.9	2.9	3.4	3.2	3.6
48-60	2.7	3.0	3.0	3.4	2.9	3.0	3.1	3.9

*Conductivity of solution extracted from saturated soil paste.

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